BNL-73439-2004-JA

# Nuclear Reaction and Structure Web Services of the National Nuclear Data Center

B. Pritychenko [a,*], A. A. Sonzogni [a], D. F. Winchell [a], V.V. Zerkin [b], R. Arcilla [a], T. W. Burrows [a], C. L. Dunford [a], M. W Herman [a], V. McLane [a], P. Obložinský [a], Y. Sanborn [a], J. K. Tuli [a]

[a] *National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY 11973-5000, U.S.A.*

[b] *Nuclear Data Section, International Atomic Energy Agency P.O. Box 100, Wagramer Strasse 5, A - 1400 Vienna, Austria*

**Abstract**

The mission of the National Nuclear Data Center (NNDC) includes collection, evaluation, and dissemination of nuclear physics data for basic nuclear research and applied nuclear technologies. In 2004, to answer the needs of nuclear data users, NNDC completed a project to modernize storage and management of its databases and began offering new nuclear data Web services. The principles of database and Web application development used at NNDC are described. Examples of nuclear structure, nuclear reaction and bibliographical database applications along with a number of nuclear science tools and codes are also presented.

*Key words:* Nuclear reaction data, Nuclear structure data, ENDF, ENSDF and NSR databases, Web services.
*PACS:* 01.52.+r, 89.20.Hh, 29.50.+v, 29.85.+c, 01.30.Tt, 25.10.+s, 21.10.-k

* Corresponding author,
*Email addresses:* pritychenko@bnl.gov (B. Pritychenko), sonzogni@bnl.gov (A. A. Sonzogni), winchell@bnl.gov (D. F. Winchell), v.zerkin@iaea.org (V.V. Zerkin), arcilla@bnl.gov (R. Arcilla), burrows@bnl.gov (T. W. Burrows), dunford@bnl.gov (C. L. Dunford), mwherman@bnl.gov (M. W Herman), vml@bnl.gov (V. McLane), oblozinsky@bnl.gov (P. Obložinský), tuli@bnl.gov (J. K. Tuli).

*21 December 2004*

## 1 Introduction

Nuclear data activities started at Brookhaven National Laboratory (BNL) in 1952 in a group that would become the National Nuclear Data Center (NNDC) in 1977 [1]. The center's objective is to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and applied nuclear technologies. The NNDC maintains and contributes to the nuclear structure (ENSDF, XUNDL, NSR) and reaction (ENDF, CSISRS, CINDA) databases[1] as well as several databases derived from these primary databases. The center prepares photo-ready copy for Nuclear Data Sheets journal, publishes Nuclear Wallet Cards booklets and neutron cross sections reference books formerly known as BNL-325 [2–4] and provides coordination and maintains databases for the Cross Section Evaluation Working Group (CSEWG) and the US Nuclear Data Program (USNDP) [5,6].

The NNDC has been providing remote electronic access to its databases and other information since 1986. Access was originally by modem and *via* HEPNET, the US Department of Energy-sponsored High Energy Physics Network which employed the DECNET protocol, and later the TCP/IP protocol. Remote login *via* Telnet was used on HEPNET and the INTERNET. This electronic service was hosted on DEC computers using the VMS operating system and Oracle CODASYL DBMS database software. Implementation of the World Wide Web protocol started in 1994. The Web service was based on the Ohio State University Web server. During 2003, users from more than 11000 organizations visited NNDC's Web site and made $3.38\times10^5$ database retrievals[2], a 17 % increase compared to year 2002.

This system has proven to be robust and scalable, providing excellent customer service for more than 18 years. However, there have been dramatic information technology developments over the last 15 years. The Open VMS operating system and CODASYL DBMS database software did not keep pace with these technological advances. It became increasingly difficult to support the NNDC Web site, satisfy all cyber security requirements, redundancy, international compatibility, and the future growth requirements with the existing system. The current industry standards are largely based on UNIX operating system, Relational Database Management System (RDBMS) software, Structured Query Language (SQL), and Java programming language.

In order to improve the quality of nuclear data services and take advantage of latest software and hardware developments, the NNDC started to work

[1] A complete description of nuclear data, software industry terms and acronyms, is presented in the Appendix 1.

[2] NNDC statistics include only strictly defined successful database retrievals. Web page visits are not counted.

on a migration project in 1999, following a basic assessment of future options. This exploratory work culminated at an International Workshop on Relational Database and Java Technologies for Nuclear Data, held at BNL, September 11-15, 2000 [7].

As a result of the workshop, the NNDC in partnership with the IAEA's Nuclear Data Section [8] embarked on a project to migrate its databases to a UNIX-based relational database environment and significantly upgrade Web Services employing the latest technologies [9]. The migration project was successfully completed and the new NNDC nuclear data Web service made available to the public in April 2004.

In the following sections, we present current status and results of the database migration project, which creates a foundation for the next generation of nuclear data Web services. First, we describe hardware and software computer environments, followed by software application developments and careful analysis of Web implementations.

## 2 New NNDC Computer Environment

The new NNDC computer environment is based on DELL/Linux platforms which includes Sybase relational database software and extensive use of Java technologies [10–12].

### *2.1 NNDC Computer Hardware and Software*

To provide more robust, scalable architecture, satisfy cyber security requirements and protect nuclear data services from a single-point failure, the Web server and two database servers (primary and secondary) are physically separated. The Web server is connected to the secondary database server while the primary database server is used for updates which are later propagated to the secondary server. All Java and Web site testing and development are performed on a working server that closely replicates the software environment installed on the Web server. The schematic view of the new system is presented in Fig. 1.

The new system consists of two database servers (DELL PowerEdge 6600, 2x2.8 GHz Intel Xeon processors, 6 GB RAM, 15 kRPM hard drive), a Web server (DELL PowerEdge 2650, 2x2.8 GHz Intel Xeon processors, 4 GB RAM), and a working server (DELL PowerEdge 4600, 2x2.8 GHz Intel Xeon processors, 8 GB RAM). The database servers are running Sybase ASE 12.5 RDBMS

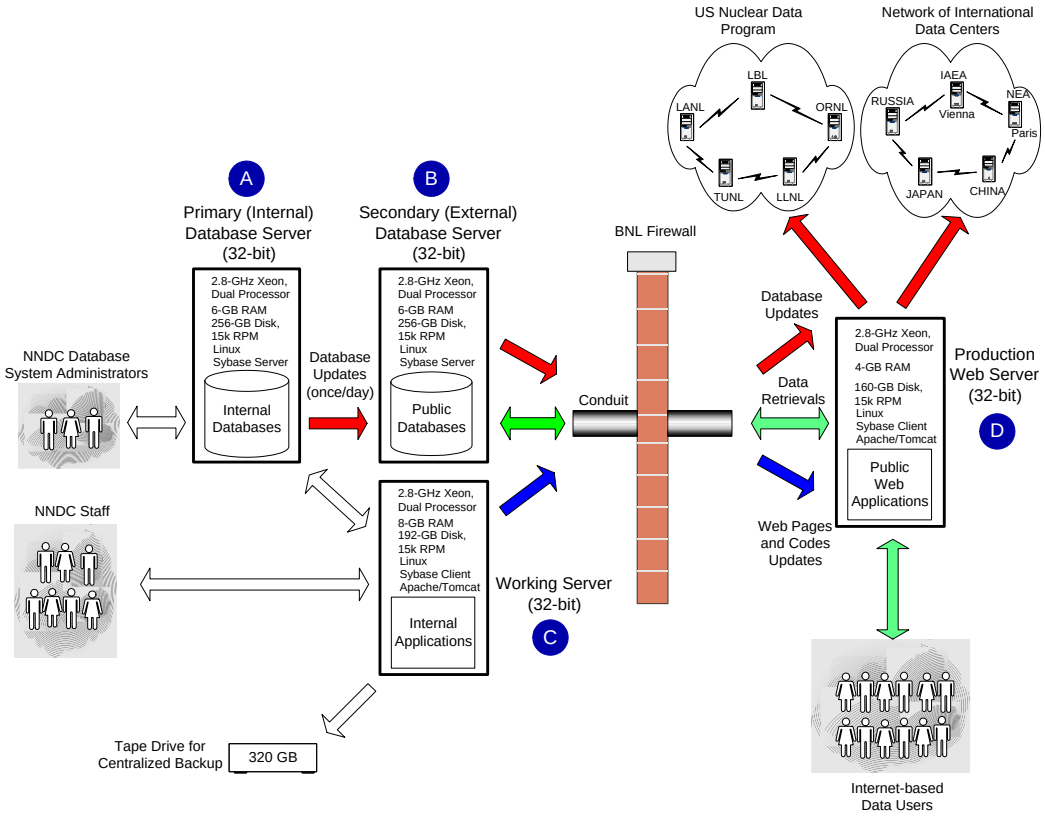


Fig. 1. Schematic view of the NNDC database computer system. New nuclear data content is propagated from primary (A) to secondary (B) database server which is connected to the Web server (D). Working server (C) is mostly used as Java testing and development environment.

software, while the Web and working servers have the Apache 2.0.51/Tomcat 4.1.27/mod_jk 1.2.6 [13,14] Web production environment installed. All servers are running the Red Hat Linux operating system.

### *2.2 NNDC Database and Web Software Application Development*

The NNDC databases were migrated using the hardware and software described above. Typically each database migration task was composed of the following five components

- Schema design
- Data loading, update and general maintenance program development
- Data preparation and quality control program development
- Web-based retrieval development
- Transfer of production activities to Linux/Sybase environment

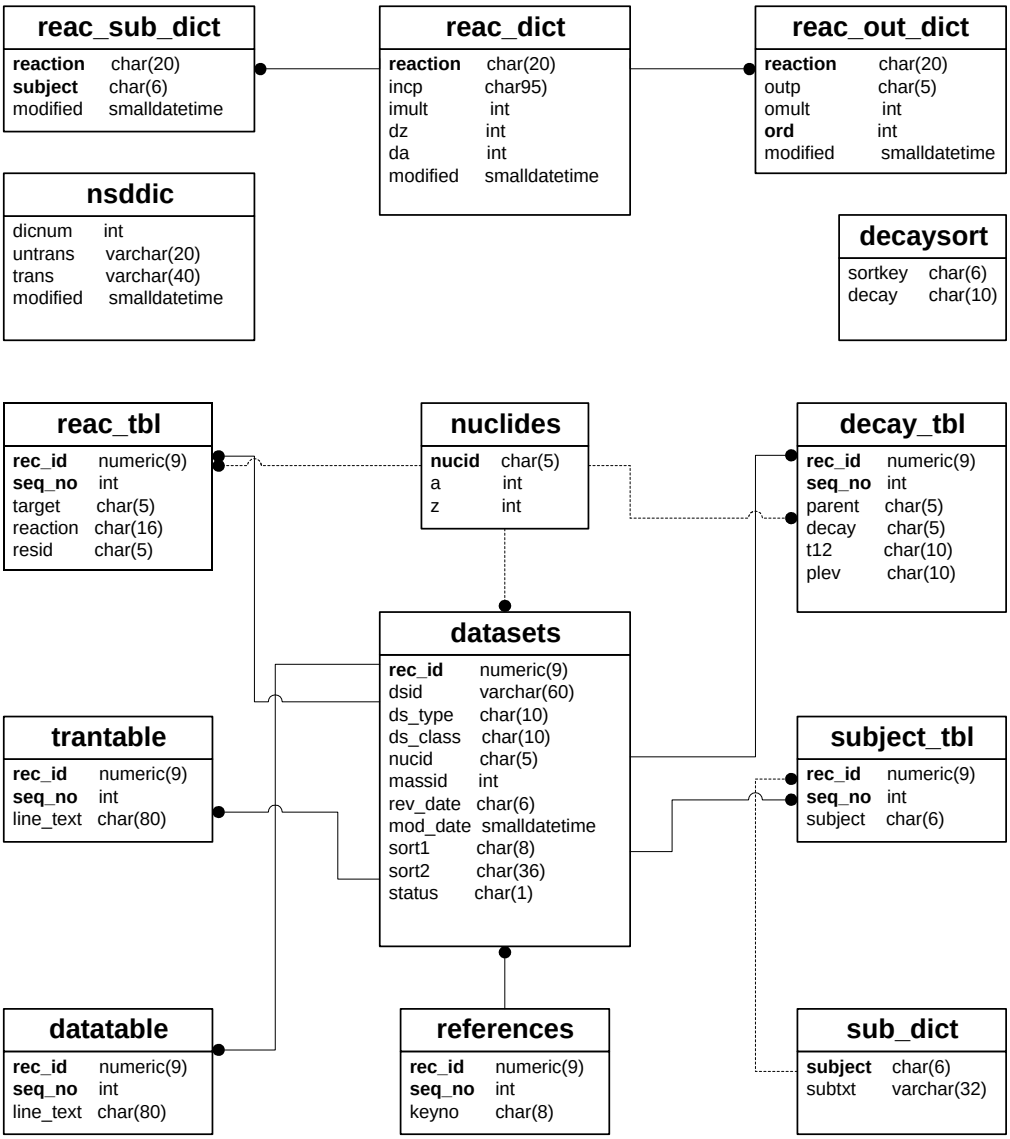


Fig. 2. Example of relational database schema. The ENSDF database schema consists of 14 tables and 12 relationships which enforce referential integrity between tables.

The database schema[3] design and development were determined by the particular database requirements; each database consists of tables, indexes, and relationships with enforced referential integrity. As an example, the ENSDF database schema [16,17] is shown in Fig. 2. In designing the new database structures, it was important to maintain all previous functionality, and to be

[3] The overall description of the database logical structures that is defined by the data definition language [15].

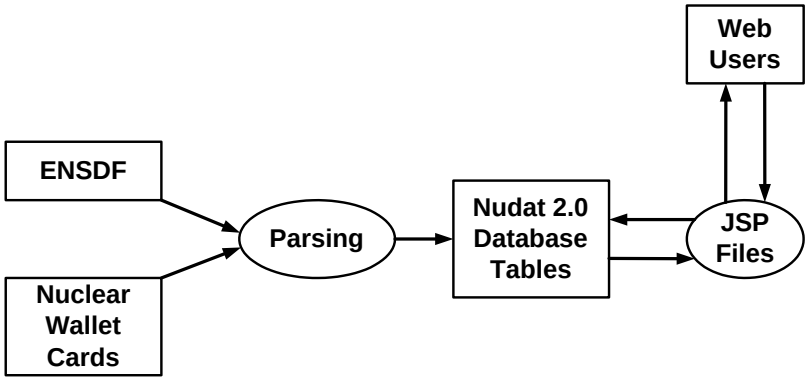


Fig. 3. Schematic view of NuDat database application design. Java Server Pages (JSP) technology provides ENSDF and Nuclear Wallet Cards database content for NuDat 2.0 Web users.

able to retrieve data in the legacy ASCII text "exchange" format.

A combination of Java codes with embedded SQL statements is used for database loads, updates, maintenance, data preparation, and quality control tasks. Most of the Web applications were completely re-written using Java Server Pages (JSP), Java Servlets, and Javascript technologies to provide up-to-date, user-friendly Web interfaces for nuclear data users. JSP Web technologies are based on JavaBeans specification for Java classes, which provides Web applications with data access and retrieval methods [12]. User-friendly JSP architecture for NuDat 2.0 database application [18] is shown in Fig. 3. In addition to new codes, many legacy Fortran codes were modified to access the new databases.

The new hardware/software system went into operation and has demonstrated high performance and reliability with a down time of less than 1%.

## 3 Nuclear Data Portal, www.nndc.bnl.gov

New Web interfaces integrated with relational databases created a Nuclear Data Portal launched on April 19, 2004. The portal is a Web-based interface which gives users access to all Web and database applications through a single screen on their computer. The Nuclear Data Portal contains nuclear structure, decay and reaction data, as well as bibliographical information. Its major features include:

- A new generation of nuclear data services using new hardware architecture based on robust and scalable DELL servers running Linux and relational database software (Sybase)
- Java solutions for Web applications

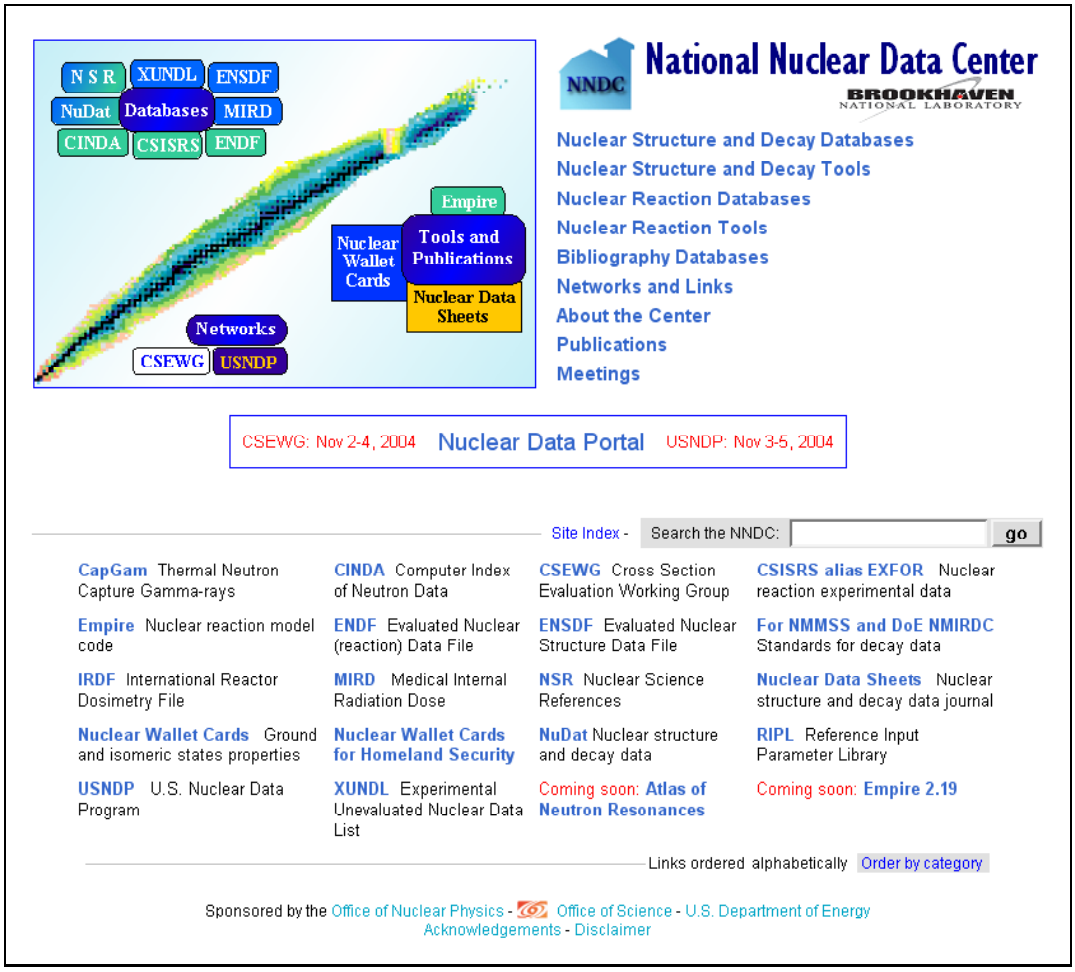


Fig. 4. Front page of the NNDC Web Services: Nuclear Data Portal. All elements of the page, including graphic images, are hyperlinked.

- Easy to navigate, active Graphic User Interfaces (GUI)
- A Google search engine and site index for NNDC documents
- New Web interfaces for CINDA, ENDF, CSISRS, ENSDF, NSR, NuDat, and XUNDL nuclear databases
- On-line query forms for information searches; results are presented in tables and interactive plots
- Numerous nuclear science tools, codes, applications, and links

The new Web-based nuclear data retrieval system or Nuclear Data Portal is tightly integrated with nuclear reaction (CSEWG) and structure (USNDP) evaluations and compilation efforts. The portal is shown in Fig. 4. The new Nuclear Data Portal has resulted in a significant increase in the NNDC Web data retrievals compared with the previous service. Fig. 5 summarizes results for Web data retrievals. Results for five major databases indicate that data retrievals for May - October of 2004 *vs.* May - October of 2003 increased for CSISRS/EXFOR by 96%, ENDF by 56%, ENSDF by 81%, NSR by 15% and NuDat by 306%. The relatively small increase for NSR database reflects the

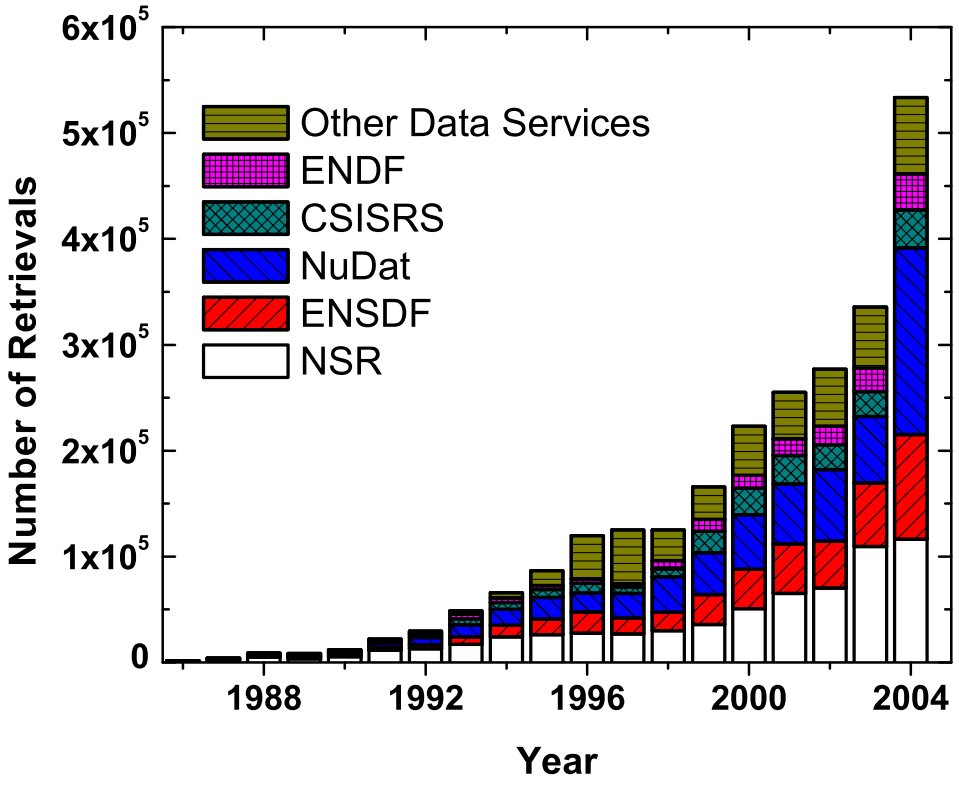


Fig. 5. Electronic nuclear data retrievals from the NNDC over the last 19 years. Data retrievals for 2004 are estimated.

fact that a Java version of NSR was available in 2003 with a 15% annual growth. If this trend continues, there will be about $6\times10^5$ retrievals in 2005. NNDC statistics include the data retrievals only and do not count any Web page access that does not result in information being retrieved. For more explanation about the statistics, see Refs. [19,20].

## 4 Nuclear Reaction Web Services

Nuclear reaction data services were substantially improved to provide a better access to reaction data evaluations and compilations [21]. New Web interfaces for the Evaluated Nuclear Data File (ENDF), the nuclear reaction experimental data (CSISRS/EXFOR), and the Computer Index of Neutron DAta (CINDA) databases, developed in collaborative effort with the IAEA's Nuclear Data Section [8], provide a wide range of options for data retrievals and analysis using standard and interpreted text formats as well as graphic tools. New nuclear reaction services distinguish themselves *via* the simple manner

of creating on-line database queries and the extensive use of graphics. A brief description of the reaction databases is presented below.

### *4.1 ENDF, www.nndc.bnl.gov/endf*

Evaluated Nuclear Data File: The ENDF reaction database contains recommended data from the United States ENDF/B-VI library [22] as well as from the other international evaluated nuclear reaction libraries: BROND, CENDL, JEFF, and JENDL [23–26]. The data are stored in the ENDF-6 format and include most nuclides of practical relevance (328 in total for ENDF/B-VI) for neutron-induced reactions up to 20 MeV. Some evaluations extend up to 150 MeV. This data serves as the principal input for neutronics calculations, including nuclear reactor design and operation, national security, criticality safety, accelerator design, radiation protection, radiotherapy, and detector simulation.

The evaluated nuclear reaction database GUI consists of two retrieval options:

- Standard request supports a basic search on target, reaction, product and quantity
- Advanced request allows the selection of the projectile sub-library (NSUB), reaction (MT) and quantity (MF), laboratory, author, target and product range

ENDF output is available in graphic and text formats. A plot of the result for a standard request for neutron-induced fission cross section of $^{235}$U is shown in Fig. 6. The current version of the ENDF library is ENDF/B-VI.8; the ENDF/B-VII library should become available by the end of 2005.

### *4.2 CSISRS alias EXFOR, www.nndc.bnl.gov/exfor*

Cross Section Information Storage & Retrieval System: the CSISRS, alias EXFOR (EXchange FORmat) data library [27] contains experimental nuclear reaction data for incident neutrons, charged particles, and photons. It includes more than 14000 experiments and covers nearly all of neutron-induced reaction experimental data up to the pion threshold. The library is less complete for charged particle induced reactions (in general A $\leq$ 12) and photon experiments. In the recent years, the number of charged particles compilations is rising faster than others. The content of the CSISRS database, compiled over many years, is shown in Fig. 7. The EXFOR compilations are coordinated by the Nuclear Reaction Data Centers Network (NRDC) [28].

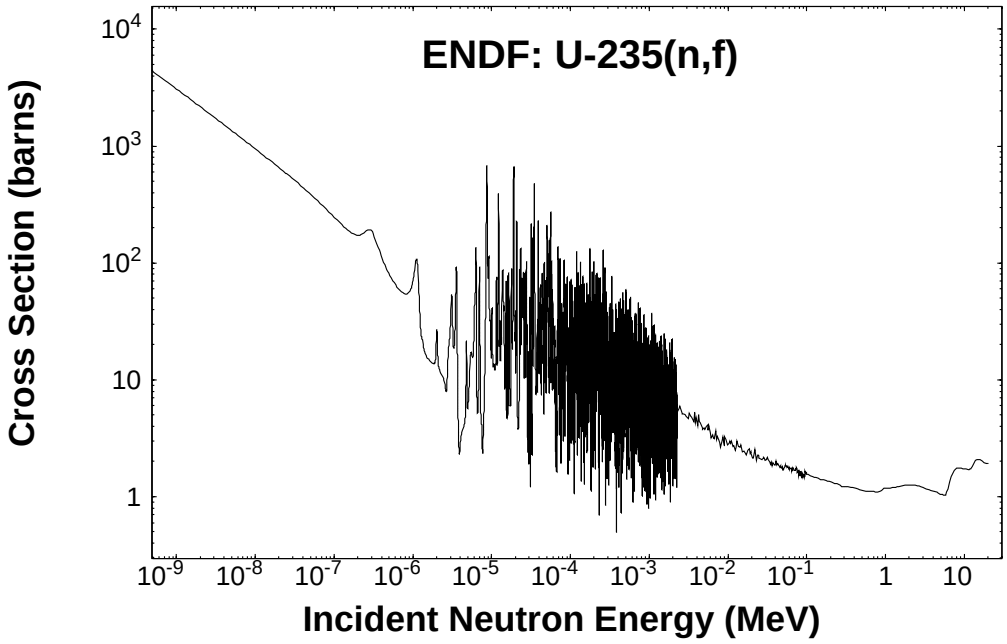


Fig. 6. Example of a plot of $^{235}$U(n,f) cross section retrieved from the ENDF/B-VI.8 library.

The CSISRS/EXFOR library GUI consists of three retrieval options namely standard, extended, and advanced requests:

- Standard request is a simple search using the primary search criteria such as target, reaction, product, quantity, energy range, authors, publication year, and accession number
- Extended request includes standard request search criteria and additional options to search for first author, country, institute, compilation date, and references
- Advanced request includes extended request search criteria and additional options for keyword and reaction subfield searches

An example of a standard request for the cross section of $^{99}$Tc(n,$\gamma$)$^{100}$Tc reaction, important for radioactive waste transmutation, is shown in Fig. 8.

### *4.3 CINDA, www.nndc.bnl.gov/cinda*

Computer Index of Neutron DAta: The CINDA database contains neutron-induced reaction bibliographic information, including experimental, theoretical, and evaluated references [32]. It contains references to $2.75\times10^5$ reactions from $5.5\times10^4$ works primarily compiled by members of the NRDC [28].

The CINDA database GUI consists of a single retrieval option, standard re-

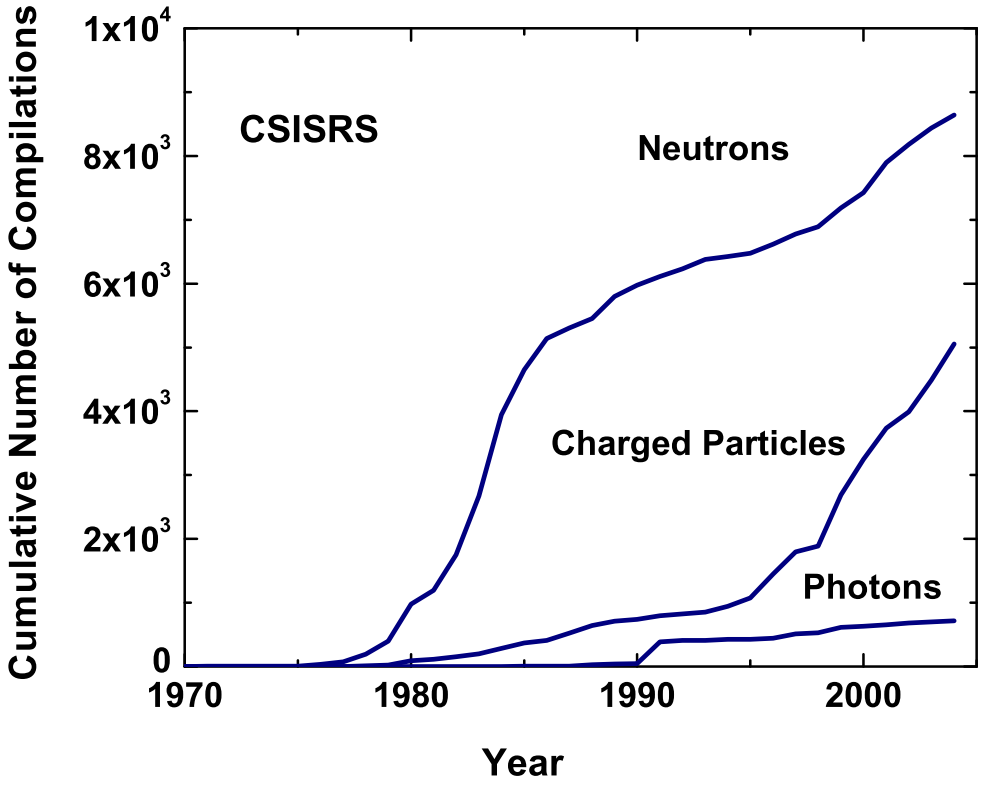


Fig. 7. Compilations of nuclear reaction experimental data into CSISRS database over the last 30 years.

quest. It allows on-line queries and searches for nuclear data publications. CINDA retrievals have a direct link to EXFOR compilations.

## 5 Nuclear Structure Web Services

Nuclear structure Web services were significantly upgraded to improve capabilities and user friendliness for the Evaluated Nuclear Structure Data File (ENSDF), Nuclear structure and decay Data (NuDat), eXperimental Unevaluated Nuclear Data List (XUNDL), Nuclear Science References (NSR) and Medical Internal Radiation Dose (MIRD) databases [16,18,33–35]. The new ENSDF Web services significantly improve and simplify ENSDF datasets retrievals, while a new NuDat 2.0 Web service enhances search and presentation capabilities for nuclear data, and provides a more convenient way to search for specific levels and $\gamma$-ray energies.

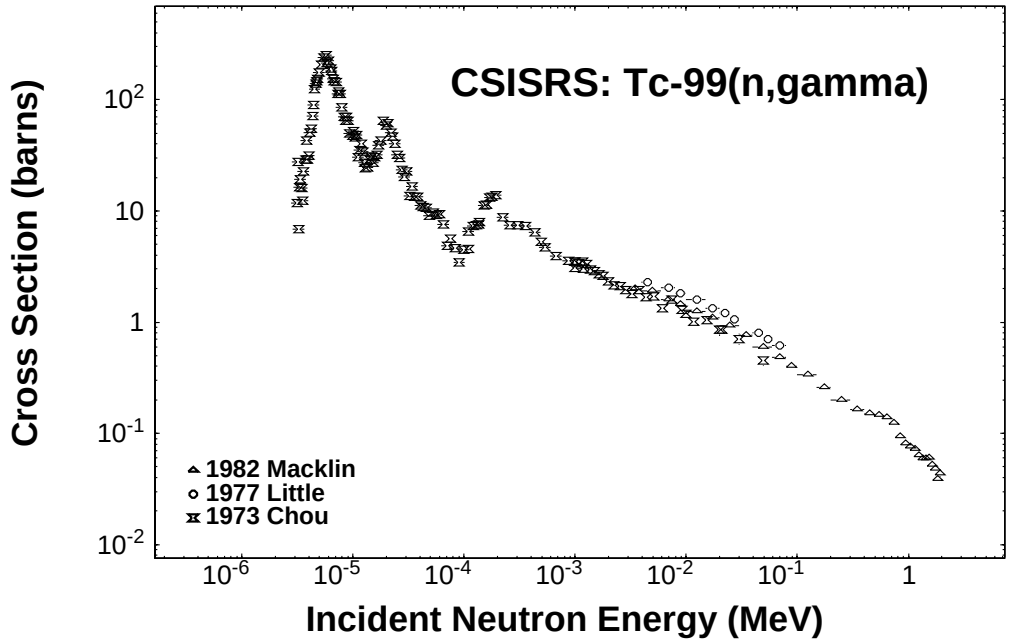


Fig. 8. Example plot of experimental data for the $^{99}$Tc(n,$\gamma$)$^{100}$Tc reaction retrieved from CSISRS. Data points refer to three different experiments [29–31].

### *5.1 ENSDF, www.nndc.bnl.gov/ensdf*

Evaluated Nuclear Structure Data File: The ENSDF evaluated nuclear structure and decay database contains recommended data for all nuclides, currently 2920, organized in over 15250 individual datasets [17]. It serves as principal source of data for nuclear structure research, nuclear spectroscopy applications, the databases MIRD and NuDat, and publications such as Table of Isotopes [36]. Nuclear structure information in the ENSDF database is organized by dataset. Each dataset contains evaluated nuclear structure information from reaction or decay and conforms to the internationally adopted ENSDF format [16,37,38], which permits further processing by a large number of existing programs. Contributions to ENSDF come from evaluators of the international network of Nuclear Structure and Decay Data (NSDD) [39].

New features of the ENSDF Web interface include:

- Simultaneous data searches between ENSDF and XUNDL
- Web retrievals based on indexed reaction quantities
- Web retrievals based on indexed decay quantities
- ENSDF dataset links to NSR references

The new ENSDF Web interface allows extraction of datasets based on specific quantities. As an example, datasets for neutron-rich nucleus of $^{178}$Hf [40] is

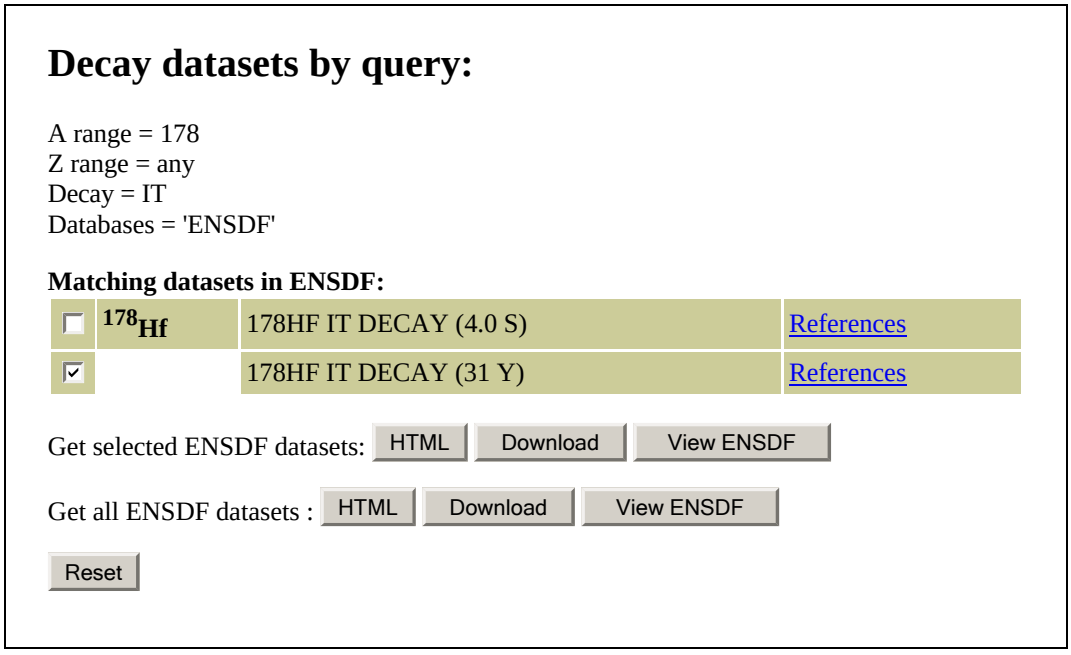


Fig. 9. ENSDF dataset retrieval for isomeric transition data and mass 178 provides an access to $^{178}$Hf nuclear structure data and NSR references.

shown are Fig. 9. Fig. 10 shows the content of the ENSDF dataset for $^{178}$Hf in HTML format.

### *5.2 XUNDL, www.nndc.bnl.gov/xundl*

eXperimental Unevaluated Nuclear Data List: XUNDL contains experimental nuclear structure and decay data compiled from more than 1100 recent articles. XUNDL was created in 1998 and compiled primarily by the Nuclear Data Group at McMaster University, Canada [33] in the ENSDF format.

There is a tighter integration of the ENSDF and XUNDL databases allowing the use of common interface. Search parameters include nuclide, nuclear reaction, and nuclear decay. Datasets may be browsed by nuclide or by mass number. As of September 24, 2004, XUNDL contained 1326 datasets for 916 nuclides.

### *5.3 NuDat, www.nndc.bnl.gov/nudat2*

Nuclear structure and decay Data: NuDat contains evaluated (recommended) nuclear structure and decay data for more than 2900 nuclides, with about $1.38\times10^5$ levels, $2.0\times10^5$ $\gamma$-ray energies, *etc.* The NuDat software application was completely redesigned and uses the latest Java graphic technologies. Cur-

**$^{178}$Hf** **$^{178}$Hf Isomeric Transition Decay (31 y) 1980Va04,1976De20,1968He10** **199408**

Published: 1994 Nuclear Data Sheets.

**$^{178}$Hf Parent:** $E_x$=2446.0 *4*; $J^{\pi}$=16+; $T_{1/2}$=31 y *1*; %Isomeric Transition=100

**History**

| Date | Type | Author | Citation | Cutoff Date | Comments |
|---|---|---|---|---|---|
| 22-Jul-1999 | Format Corrections | J. Tuli | | | ADDED P RECORD |
| | Full evaluation | E. Browne | Nuclear Data Sheets 72,221 (1994) | 1-Jul-1993 | |

Additional documentation [0]

Others: 1993GaZY, 1992Og01, 1992Yu02, 1991Ch06, and 1973He19.

See 1992Og01 for production of microweight quantities of $^{178}$Hf(31 years) using the $^{176}$Yb($^{4}$He,2n) reaction, and 1991Ch06 for a calculation of cross-sections for production of $^{178}$Hf(31 years) with fast neutrons.

See 1992Gi08 for a measurement of possible parity and time reversal violations of the 88-keV γ-ray transition.

Measured Eγ, Iγ, ce, γγ coin. Detectors: Ge(Li) high purity, Ge(Li) anti-Compton, Si(Li) (1980Va04).

Measured Eγ, Iγ, γγ coin, ce. Detectors: Ge(Li) anti-Compton, scin, Si(Li) (1976De20).

Measured Eγ, Iγ, γγ coin. Detectors: Ge(Li), scin (1968He10).

Measured γγ(θ), detector: array of seven Ge(Li) detectors. Determined δ (1993Tl01).

**$^{178}$Hf levels**

| $E_{level}$[#] | $J^{\pi}$ | $T_{1/2}$ | Comments |
|---|---|---|---|
| 0.0[@] | 0+ | | |
| 93.185[@] *5* | 2+ | | |
| 306.619[@] *6* | 4+ | | |

Fig. 10. ENSDF data retrieval for $^{178}$Hf includes the full evaluation of E. Browne [41] corrected by J. Tuli in July 1999. The first lines of the corresponding HTML document are shown here.

rently it is the most popular application on Nuclear Data Portal [42]. The new NuDat 2.0 software supports searches on parameters such as nuclide or parent, energy levels, decay modes, $J^{\pi}$, $T_{1/2}$ and $E_{\gamma}$. Enhancements include:

- A Chart of the Nuclides interface for ground and metastable state properties
- Options to obtain tables and interactive level schemes of the adopted data contained in ENSDF and Nuclear Wallet Cards
- Search for $\gamma\gamma$-coincidences

The NuDat 2.0 main page includes interactive chart of nuclei. A cell in a chart represents a known nuclide with the number of neutrons on the horizontal axis and the number of protons on the vertical axis. The color of the cell indicates the ground state half-life or predominant decay mode. NuDat 2.0 interactive chart of nuclei is shown in Fig. 11. NuDat outputs include a complete list of levels and level schemes. The level scheme for selected levels in $^{178}$Hf is shown in Fig. 12.

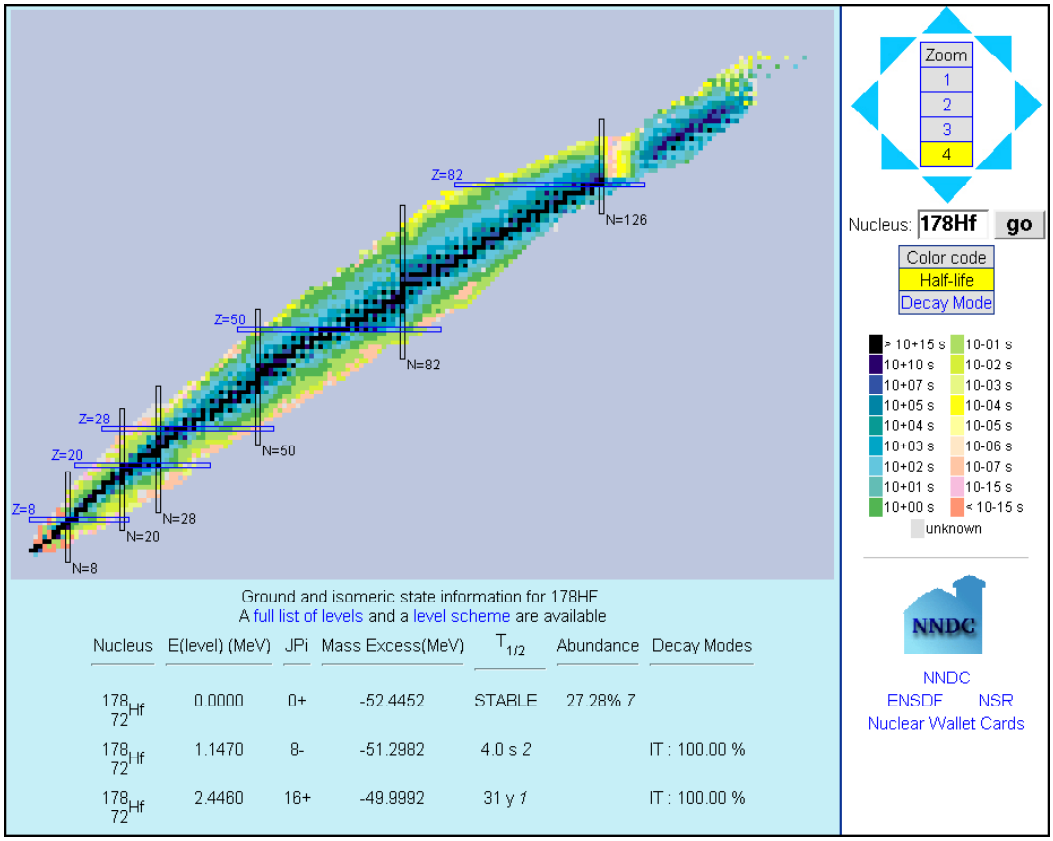


Fig. 11. NuDat 2.0 data retrieval for $^{178}$Hf displays ground and isomeric state information, see bottom of the figure. A full list of levels and level scheme are also available.

### *5.4 NSR, www.nndc.bnl.gov/nsr*

Nuclear Science References: NSR is an indexed bibliography of nuclear physics papers and reports containing over $1.75\times10^5$ nuclear science references, indexed according to content. The contents span almost 100 years of research, and currently covers 75 journals with about 4200 new articles added per year. The database is updated on a weekly basis to stay current with published literature.

In addition to standard reference, author, and title information, most entries in the NSR database include "keyword abstracts" to allow a search for references relevant to specific quantities or topics. Where available, digital object identifier (doi) links to publisher's pages are provided, see bottom of Fig. 13. Quick retrievals by author or nuclide, as well as indexed or text searches, and keynumber retrievals, are available. Search parameters for indexed retrievals include nuclide, author, subject, reaction, target, incident or outgoing particle, and topic. These parameters can be combined to create on-line queries and produce more focused results. Often retrieved NSR entries are followed

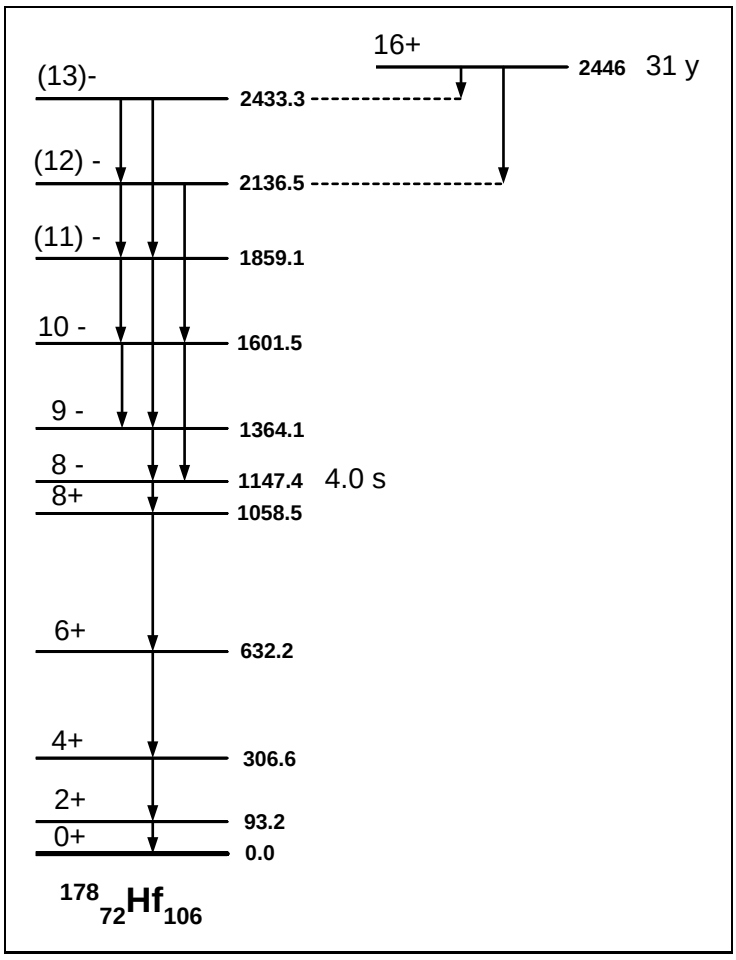


Fig. 12. NuDat 2.0 level scheme of $^{178}$Hf displays $16^+$ and $T_{1/2}$ = 31 y isomer of $^{178m2}$Hf. The isotope decays to $(13)^-$ and $(12)^-$ states of $^{178}$Hf.

by links to the publisher's pages, see Fig. 13. It also contains links to ENSDF and XUNDL databases, where relevant.

### *5.5 MIRD, www.nndc.bnl.gov/mird*

Medical Internal Radiation Dose: MIRD contains recommended nuclear decay data for over 2100 radionuclides extracted from ENSDF, which is processed by the program RadList [37,43] and presented in the Medical Internal Radiation Dose format.

## NSR Query Results

Publication year range : 1910 to 2005
Primary references only.

Output year order : Ascending
Format : Normal

NSR database version of Dec 03, 2004.

Indexed quantity search: Author=PRITYCHENKO AND Nuclide=22O

Found 1 matches.

Back to query form

**2000TH11**

Phys.Lett. 485B, 16 (2000)

P.G.Thirolf, B.V.Pritychenko, B.A.Brown, P.D.Cottle, M.Chromik, T.Glasmacher, G.Hackman, R.W.Ibbotson, K.W.Kemper, T.Otsuka, L.A.Riley, H.Scheit

*Spectroscopy of the $2_1^+$ State in $^{22}O$ and Shell Structure Near the Neutron Drip Line*

NUCLEAR REACTIONS $^{197}$Au($^{22}$O, $^{22}$O'), E=50.6 MeV/nucleon; measured Egamma, Igamma, sigma. $^{22}$O level deduced excitation B(E2), shell structure. Secondary beam from $^{40}$Ar fragmentation. Level systematics in neighboring isotopes discussed.

doi: 10.1016/S0370-2693(00)00720-6

Fig. 13. Results of NSR indexed request retrieval for author = "PRITYCHENKO" and nuclide = "22O" contains list of authors, keyword abstract and digital object identifier "10.1016/S0370-2693(00)00720-6" used to access publisher's pages.

## 6 Tools and Publications

NNDC provides access to many other resources of interest to the nuclear scientific community. These include calculational tools, computer codes, data libraries, and publications. Nuclear reaction and structure tools and publications, such as Empire (see next paragraph), Nuclear Wallet Cards, Q-value Calculator (QCalc) and Thermal Neutron Capture $\gamma$-rays (CapGam) were upgraded and integrated into the Nuclear Data Portal. The portal also contains some applications that were developed by third parties such as atomic masses data library [44] and temperature dependent ENDF/B-VI.8 cross section library Point 2004 [45].

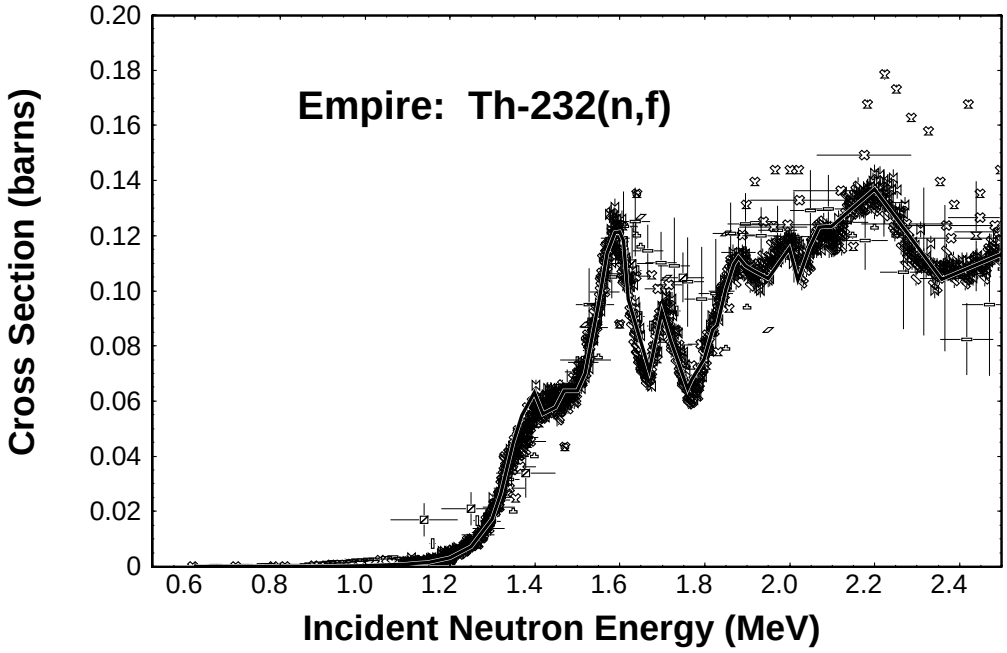


Fig. 14. $^{232}$Th(n,f) cross section calculated with the recent version of Empire 2.19. Experimental data are taken from 12 different references [27].

### *6.1 Empire, www.nndc.bnl.gov/empire*

Empire is modular nuclear reaction code for advanced calculation of nuclear reactions using various theoretical models [46]. It consists of a number of linked FORTRAN codes, input parameter libraries, and the experimental data library (CSISRS/EXFOR). Application of Empire-2.19 code for the $^{232}$Th(n,f) reaction cross section calculation is shown in Fig. 14.

New features of Empire 2.19, to be released in 2005 include:

- Fission with under-barrier effects in terms of optical model
- Multi-modal fission
- Photo-nuclear reactions
- Reactions on excited targets
- Exact treatment of exclusive spectra
- Improved algorithm for recoil spectra
- Suite of $\gamma$-ray strength functions from RIPL-2 [47]
- Exciton model with cluster emission (Iwamoto-Harada) [48]

### *6.2 Nuclear Wallet Cards, www.nndc.bnl.gov/wallet*

The Nuclear Wallet Cards publication contains up-to-date ground and isomeric states properties of all known nuclides. The sixth edition of Nuclear Wallet Cards [49] has been adopted by the U.S. Department of Energy, Nuclear Materials and Safeguards System as their decay data standard.

A version tailored for Homeland Security needs is also available [50]. Nuclear Wallet Cards for Radioactive Nuclides include nuclear properties of $T_{1/2} \geq 1$ h nuclides and consists of two tables. The first one provides half-life, major radiations, and major $\gamma$-ray information for 737 nuclides. The second table contains information on 944 $\gamma$-rays and parent nuclides sorted by energy from 101 to 2951 keV.

In addition to Web versions, Nuclear Wallet Cards are distributed as booklets and as Palm Pilot applications. The PDA version requires Palm OS 3.0 or higher and mobiledb database program installed. The mobiledb database program can be replaced with a FreewarePalm mobiledb-lite program. All recent versions of Nuclear Wallet Cards are available in the PDA format.

### *6.3 Nuclear Data Sheets, www.nndc.bnl.gov/nds*

NNDC edits and produces the *Nuclear Data Sheets* journal. The journal, published by Elsevier, is devoted to the publication of evaluated nuclear structure and decay data. These articles contain recommended values based on a careful evaluation and analysis of all available experimental results dealing with nuclear properties. An index to recent issues of the *Nuclear Data Sheets* is also available on the Web.

### *6.4 Thermal Neutron Capture $\gamma$-rays (CapGam), www.nndc.bnl.gov/capgam*

Recently updated, the thermal neutron capture $\gamma$-rays data on this site are extracted from ENSDF and consist of target and $\gamma$-energy ordered tables for 256 target nuclides up to 12 MeV in energy.

### *6.5 Q-value Calculator, www.nndc.bnl.gov/qcalc2*

QCalc is an NNDC software application for the calculation of decay or reaction Q-values and threshold energies using the data from 2003 Atomic Mass

Evaluation [44]. The latest version of QCalc is written in Java.

### *6.6 Physics Codes (PhysCo), www.nndc.bnl.gov/physco*

PhysCo allows interactive calculations of $\beta^{\pm}$ and electron-capture log *ft* values, average $\beta$ energies or $\gamma$-ray internal conversion coefficients using the programs LOGFT [51] and HSICC [52], respectively. One must upload a file in the ENSDF format to use these tools.

### *6.7 Atomic Masses, www.nndc.bnl.gov/amdc*

Since 2004, NNDC is the primary host for the data distributed by the Atomic Mass Data Center (AMDC), Paris, France. The atomic masses data library is maintained by G. Audi to provide the data associated with the 2003 atomic mass evaluation [44]. Archival versions of earlier evaluations are also available.

### *6.8 Point 2004, www.nndc.bnl.gov/point2004*

Point 2004 is a temperature dependent version of ENDF/B-VI, Release 8, nuclear data library developed by D.E. Cullen [45]. It consists of data at eight nuclear reactor temperatures between 0° and 2100° Kelvin and six astrophysics temperatures between 0.1 eV and 10 keV.

## 7 Conclusion

The new Nuclear Data Portal of the National Nuclear Data Center (www.nndc.bnl.gov) is a result of the successful completion of the database migration project that was carried out by NNDC for U.S. Nuclear Data Program. The Nuclear Data Portal is based on a DELL/Linux solution with extensive use of Sybase relational database management software, SQL, and Java Web technologies.

The portal brings together nuclear structure and reaction Web services, publications, and tools. It provides a unique access to many nuclear physics resources and creates a single site where nuclear data users can find tools and data to help solve science, industry and homeland security problems and challenges.

Use of electronic nuclear data services continues to grow in a near-exponential way. This is illustrated in Fig. 5, showing the growing number of downloads from the NNDC databases since 1986, a trend supported by similar experience of other nuclear data centers. It appears that the user demand is far below saturation as demonstrated by accelerated use of new services in 2004. We are confident that the portal has considerable potential to meet growing demands in the next years. On the other hand, the present paper demonstrates that nuclear databases, if utilized in a wise and innovative way, offer opportunities for far more proficient service in future.

## Acknowledgements

We are grateful to D. Rochman and M. Blennau for a careful reading of the manuscript and useful discussions and suggestions. This work was funded by the Office of Nuclear Physics, Office of Science of the U.S. Department of Energy, under Contract No. DE-AC02-98CH10886 with Brookhaven Science Associates, LLC.

## Appendix 1

Nuclear data, software industry and information technology terms and acronyms are presented in the Table 1:

Table 1

| Term or Acronym | Description | Reference |
|---|---|---|
| Apache | HTTP server | [13] |
| ASE 12.5 | Adaptive server enterprise 12.5, also see Sybase | [10] |
| BROND | Russian Evaluated Nuclear Data Library (reacton) | [23] |
| CENDL | Chinese Evaluated Nuclear Data Library (reaction) | [24] |
| CINDA | Computer Index of Neutron DAta | [32] |
| CODASYL DBMS | Oracle 6.0 database server | |
| CSEWG | Cross Section Evaluation Working Group | [5] |
| CSISRS | Cross Section Information Storage & Retrieval System | [27] |
| ENDF | Evaluated Nuclear Data File (reaction) | [22] |
| ENSDF | Evaluated Nuclear Structure Data File | [16,17] |
| EXFOR | EXchange FORmat, also see CSISRS | [27] |
| HTML | Hyper Text Markup Language | |
| HTTP | Hyper Text Transfer Protocol | |
| JEFF | Joint Evaluated Fission & Fusion file | [25] |
| JENDL | Japanese Evaluated Nuclear Data Library (reaction) | [26] |
| JSP | Java Server Pages | [12] |
| MIRD | Medical Internal Radiation Dose | [35] |
| Mod_jk | Apache - Tomcat connector | [14] |
| NRDC | Nuclear Reaction Data Centers network | [28] |
| NSDD | Nuclear Structure and Decay Data evaluators network | [39] |
| NSR | Nuclear Science References | [34] |
| NuDat | Nuclear structure & decay Data | [18] |
| PDA | Personal Digital Assistant | |
| RDBMS | Relational Database Management System | [15] |
| RIPL | Reference Input Parameter Library (reaction) | [47] |
| SQL | Structured Query Language | [15] |
| Sybase | Commercial database server | [10,11] |
| Tomcat | Servlet/JSP container | [14] |
| USNDP | United States Nuclear Data Program | [6] |
| XUNDL | eXperimental Unevaluated Nuclear Data List | [33] |

## References


[1] S. Pearlstein, Nuclear News, 13, No. 11 November (1970).

[2] S.F. Mughabghab, Atlas of Neutron Resonances, to be published by Academic Press in 2005.

[3] S.F. Mughabghab, M. Divadeenam, N. E. Holden, Neutron Cross Sections, Vol 1, Part A, Z = 1-60, Academic Press, New York, 1981. S.F. Mughabghab, Neutron Cross Sections, Vol 1, Part B, Z = 61-100, Academic Press, Orlando, 1984.

[4] V. McLane, C.L. Dunford, P.F. Rose, Neutron Cross Sections, Vol 2, Neutron Cross Section Curves, Academic Press, San Diego, 1988.

[5] Cross Section Evaluation Working Group (CSEWG),
http://www.nndc.bnl.gov/csewg (accessed December 15, 2004).

[6] United States Nuclear Data Program (USNDP),
http://www.nndc.bnl.gov/usndp (accessed December 7, 2004).

[7] Proceedings of Workshop on Relational Database and Java Technologies for Nuclear Data, Brookhaven National Laboratory, September 11-15, 2000, edited by R. Arcilla, D. Winchell, Y. Sanborn, unpublished.

[8] International Atomic Energy Agency (IAEA) Nuclear Data Section (NDS), http://www-nds.iaea.org (accessed December 15, 2004).

[9] V. Pronyaev, D. Winchell, V. Zerkin, D. Muir, R. Arcilla, J. Nucl. Sci. Tech. Suppl. 2 (2002) 1476.

[10] Sybase, Inc., http://www.sybase.com (accessed December 15, 2004).

[11] R. Rankins, J. Garbus, D. Solomon, B. McEwan, Sybase SQL Server 11 UNLEASHED, SAMS Publishing, Indianapolis, 1996.

[12] A Sun Developer Network Site, http://java.sun.com (accessed December 15, 2004). H. Bergsten, JavaServer Pages, second edition, O'Reilly & Associates, Sebastopol, 2002.

[13] The Apache Software Foundation, http://www.apache.org (accessed December 15, 2004).

[14] The Apache Jakarta project, http://www.jakarta.apache.org (accessed December 15, 2004).

[15] A.C. Lorents, J.N. Morgan, Database Systems: Concepts, Management and Applications, The Dryden Press, Orlando, 1998.

[16] J.K. Tuli, Evaluated Nuclear Structure Data File (ENSDF), Brookhaven National Laboratory Report BNL-NCS-51655-01/02-Rev (2001).

[17] D.F. Winchell, New Web-Based Access to Nuclear Structure Databases, Proceedings of Int. Conf. on Nuclear Data for Science and Technology, Santa Fe, September 26 - October 1, 2004, in print.

[18] A.A. Sonzogni, NuDat 2.0: Nuclear Structure and Decay Data on the Internet, Proceedings of Int. Conf. on Nuclear Data for Science and Technology, Santa Fe, September 26 - October 1, 2004, in print.

[19] T.W. Burrows, Proceedings of USNDP 2003 Meeting, BNL, November 6-7, 2003. http://www.nndc.bnl.gov/nndc/proceedings/2003csewgusndp/dis_rep/02Burrows.pdf (accessed December 15, 2004).

[20] Analog 5.32: How the Web works, http://www.analog.cx/docs/webworks.html (accessed December 15, 2004).

[21] V.V. Zerkin, V. McLane, M.W. Herman, C.L. Dunford, EXFOR-CINDA-ENDF: Migration of Databases to Give Higher Quality Nuclear Data Services, Proceedings of Int. Conf. on Nuclear Data for Science and Technology, Santa Fe, September 26 - October 1, 2004, in print.

[22] V. McLane, Brookhaven National Laboratory Report BNL-NCS-17541, 4th Edition (1996).

http://www.nndc.bnl.gov/nndcscr/documents/endf/endf201/endf-201.pdf (accessed December 15, 2004).

[23] A.I. Blokhin, B.I. Fursov, A.V. Ignatyuk, V.N. Koshcheev, E.V. Kulikov, B.D. Kuzminov, V.N. Manokhin and M.N. Nikolaev, Proceedings of Int. Conf. on Nuclear Data and Technology, Gatlinburg, Tennessee, USA, May 9-13, 1994; 2 (1994) 695.

[24] International Atomic Energy Agency Nuclear Data Section Report INDC(CPR)-025/L (1991);

http://www-nds.iaea.org/indc-sel.html (accessed December 15, 2004).

[25] R. Jacqmin, R. Forrest, J. Rowlands, A. Nouri and M. Kellet, J. Nucl. Sci. Technol., Suppl. 2, Vol. 1, (2002) 54.

[26] K. Shibata, T. Kawano, T. Nakagawa *et al*, J. Nucl. Sci. Technol. 39 (2002) 1125.

[27] Cross Section Information Storage & Retrieval System, http://www-nds.iaea.org/about-exfor.html (accessed December 15, 2004).

[28] Nuclear Reaction Data Centers Network, http://www-nds.iaea.org/nrdc.html (accessed Decmber 15, 2004).

[29] J.C. Chow, H. Werle, J. of Nuclear Energy 27 (1973) 811.

[30] R.C. Little, R.C. Block, Trans. of the American Nuclear Society 26 (1977) 574.

[31] R.L. Macklin, Nuclear Science and Engineering 81 (1982) 520.

[32] Computer Index of Neutron Data, http://www.nndc.bnl.gov/cinda (accessed December 7, 2004).

[33] McMaster University Data Evaluation,

http://physun.physics.mcmaster.ca/~jcw/nucexp/ (accessed December 15, 2004).

[34] D.F. Winchell, Nuclear Science References as a Tool for Data Evaluation, Proceedings of Int. Conf. on Nuclear Data for Science and Technology, Santa Fe, September 26 - October 1, 2004, in print.

[35] Medical Internal Radiation Dose, http://www.nndc.bnl.gov/mird (accessed December 15, 2004).

[36] R.B. Firestone, V.S. Shirley, C.M. Baglin, S.Y. Frank Chu, and J. Zipkin, Table of Isotopes, 8th edition, John Wiley & Sons, Inc., New York, 1996.

[37] T.W. Burrows, Nucl. Instr. and Meth. A286 (1990) 595.

[38] J.K. Tuli, Nucl. Instr. and Meth. A369 (1996) 506.

[39] International Network of Nuclear Structure and Data Evaluators, http://www-nds.iaea.org/nsdd.html (accessed December 15, 2004).

[40] B. Schwarzschild, Physics Today 57, issue 5 (2004) 21.

http://www.physicstoday.org/vol-57/iss-5/p21.html (accessed December 15, 2004).

[41] E. Browne, Nuclear Data Sheets 72 (1994) 221.

[42] Web Watch, Physics Today 57, issue 11 (2004) 34.

[43] T.W. Burrows, Brookhaven National Laboratory Report BNL-NCS-52142 (1988).

[44] A.H. Wapstra, G. Audi, and C. Thibault, Nuclear Physics A729 (2003) 337.

[45] D.E. Cullen, Lawrence Livermore National Laboratory Report UCRL-TR-202284 (2004).

[46] M. Herman, R. Capote-Noy, P. Obložinský, A. Trkov and V. Zerkin, J. Nucl.Sci. Tech. Suppl. 2 (2002) 116.

[47] Reference Input Parameter Library, http://www-nds.iaea.org/RIPL-2/ (accessed December 15, 2004).

[48] A. Iwamoto, K. Harada, Phys. Rev. C26 (1982) 1821.

[49] J.K. Tuli, Nuclear Wallet Cards, National Nuclear Data Center, Brookhaven National Laboratory, January 2000.

[50] J.K.Tuli, Nuclear Wallet Cards for Radioactive Nuclides, National Nuclear Data Center, Brookhaven National Laboratory, March 2004.

[51] N.B. Gove, M.J. Martin, Nuclear Data Tables A10 (1971) 205.

[52] R.S. Hager, E.C. Seltzer, Nuclear Data Tables A4 (1968) 1.